Reassessment of Radium and Thorium Soil Concentrations and Annual Dose Rates

U.S. Environmental Protection Agency
Office of Radiation and Indoor Air
401 M Street, SW
Washington, D.C. 20460

July 22, 1996

EPA's Office of Radiation and Indoor Air (ORIA) is reviewing key modeling assumptions and parameter values used in the Agency's draft Technical Support Document (TSD)[1] to calculate radiation doses and radionuclide soil concentrations. The scope of this review includes exposure scenarios based on current and future land use after cleanup, generic model site characteristics, and standardized default exposure factors. ORIA is particularly interested in choosing modeling assumptions that are "realistic" or "reasonable," based on site-specific information, yet fully protective of human health and the environment.

This paper presents the results of a focused reassessment of derived soil concentrations and associated annual dose rates for selected isotopes of radium (Ra-226 and Ra-228) and thorium (Th-230 and Th-232) conducted by ORIA as part of its overall review. The primary purpose of this evaluation was to assess generically dose rate levels that correspond to the 5 picocuric per gram (pCi/g) soil cleanup concentration specified under 40 CFR 192[2] for uranium and thorium mill tailings sites. This reassessment was conducted by comparing radium and thorium doses and soil concentrations calculated assuming a contaminated zone area and thickness for the model site described in the Agency's draft TSD with those computed assuming different dimensions specified under 40 CFR 192. Secondary goals of the reassessment were to calculate radium and thorium doses and soil concentrations for two new recreational exposure scenarios and for reduced gamma shielding and soil-to-plant transfer factors.

Background

Chapter 2 of the draft TSD describes the exposure scenarios used by EPA in the proposed soil cleanup rule analyses to calculate individual radiation doses and risks, and Chapter 3 presents a detailed discussion of the default exposure parameters and model site characteristics used to derive radionuclide-specific soil concentrations corresponding to target dose and risk limits. As explained in these two chapters, ORIA selected these exposure scenarios, default parameters, and model site characteristics for several reasons, including

- consistency and compatibility with current Agency guidance.

---

[1] *Radiation Site Cleanup Regulations: Technical Support Document for the Development of Radionuclide Cleanup Levels for Soil* (Review Draft). EPA 402-R-96-011 A, B, and C. Office of Air and Radiation. Sept. 1994.

[2] Title 40 of the Code of Federal Regulations, Part 192—*Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings*. U.S. Environmental Protection Agency. 48 FR 602. Jan. 5. 1983. (See specifically §192.12.) The health and environmental protection standards set forth in 40 CFR 192 are sometimes referred to as "UMTRCA standards" based on the Uranium Mill Tailings Radiation Control Act of 1978. Pub. L. 95-604. as amended, that authorized and directed EPA to establish the Part 192 standards.

- "reasonableness" with respect to intended land use and assumed exposure pathways after cleanup, and
- "representativeness" with respect to the characteristics of real and reference radiation sites.

Overall, the assumptions used in the TSD to model radiation doses and risks are "conservative" in the sense that their use will, in the vast majority of cases, overestimate the true doses and risks posed by radionuclides at specific sites. The selection of conservative assumptions was deemed necessary by EPA to capture the full spectrum of possible doses and risks associated with the diverse and highly complex universe of known and potential future radiation sites.

Since the publication of the draft TSD in 1994, ORIA has revised several of its earlier calculations and conducted new evaluations. Much of this effort has focused on reexamining the "reasonableness" and "representativeness" of modeling assumptions. Current evaluations, including those presented in this paper, are directed toward refining assumptions and analyses based on site-specific information.

Calculations

Three sets of calculations were performed to derive the soil concentrations and associated annual dose rates for selected isotopes of radium and thorium presented in Attachment 1. The first set of calculations—labeled "TSD" in Attachment 1—compares soil concentrations and dose rates presented in the draft TSD for rural residential, suburban residential, and commercial/industrial exposure scenarios[1] with comparable values derived for two new recreational exposure scenarios, playground and hunter/fisher. Under the proposed radiation site cleanup regulations, recreational scenarios like these might be recommended by the Agency for use in evaluating sites transferred (or leased) from one federal agency to another after cleanup. For calculations of radium and thorium doses and soil concentrations, both recreational scenarios assume all of the default exposure factors for rural residential exposures provided in the draft TSD, except as indicated in Attachment 2.

The second set of calculations—labeled "Calculation A" in Attachment 1—refer to the scenario based on 40 CFR 192 comparison. In this analysis, radium soil concentrations and doses were computed assuming a contaminated zone area of 100 m^2 and thickness of 0.15 m, as specified under 40 CFR 192. These results can be compared with those derived using the TSD defaults of 10,000 m^2 and 2 m, respectively. As used in 40 CFR 192, the 100 m^2 area represents a typical survey unit size, and the 0.15 m thickness represents sites contaminated with windblown uranium, radium, and thorium tailings. Further, as shown in Table 3-12 (p. 3-41) of the draft TSD, 50% of the reference sites considered in the TSD analyses had a contaminated zone thickness of about 0.15 m or less prior to remediation. After remediation, this percentage would be expected to increase.

In a general sense, the Calculation A assessment is a focused sensitivity analysis to determine the effect of varying contaminated zone area and thickness simultaneously on derived soil concentrations and associated radiation dose rates. [The effect of varying these parameters individually is discussed in detail in TSD Chapter 3.]

The third set of calculations—labeled "Calculation B" in Attachment 1—are based on the 40 CFR 192 assumptions in Calculation A and on three additional modifications: (1) the gamma shielding factor (i.e., the ratio of indoor to outdoor gamma exposure rates) was assumed to be 0.4 (60% shielding), instead of the TSD default value of 0.8 (20%); (2) the soil-to-plant transfer factor for radium was assumed to be 7.14E-03,

[1] See TSD Tables 3-1, 3-2 and 3-3 (pp. 3-4 through 3-9) and Table 7-1 (pp. 7-4 through 7-6).

instead of the TSD default value of 4.0E-02; and (3) the soil-to-plant transfer factor for lead (i.e., Pb-210, a radioactive decay product of Ra-226) was assumed to be 1.55E-03, instead of the TSD default value of 1.0E-02.

The Calculation B assessment investigated the effects of deriving soil concentrations based on values for the gamma shielding factor and radium and lead plant transfer factors that are different from, and possibly more appropriate than, the default values in the draft TSD. The modified par neter values used in this assessment are based on a recent review of the literature.[4] This review found that gamma shielding factors typically range from 0.4 (60% shielding) for above ground, lightly constructed (wood frame) homes to 0.2 (80% shielding) for brick homes. Based on this information, the review suggested that a default gamma shielding factor of 0.4 might be a more appropriate value to use at sites with soil contaminated with radionuclides than the current EPA default of 0.8[5] (20% shielding). In addition, 0.4 is comparable to the value of 0.33 (67% shielding) used by the Nuclear Regulatory Commission (NRC).[6] The review also concluded that recent scientific studies support revised soil-to-plant transfer factors of 7.14E-03 for radium and 1.55E-03 for lead—compared to the draft TSD values of 4.0E-02 and 1.0E-2, respectively, which are the default values provided in RESRAD.

All calculations focus on Ra-226, Ra-228, Th-230 and Th-232, radionuclides that occur frequently at sites subject to EPA's proposed cleanup regulations and to 40 CFR 192. As mentioned previously, soil concentration data for the rural residential, suburban residential, and commercial/industrial exposure scenarios were taken from the draft TSD (Table 7-1). Soil data for the two new recreational exposure scenarios were calculated using RESRAD Version 5.61 assuming the parameter values shown in Attachment 2.

Results

The results of the three calculational sets are presented in Attachment 1 and discussed below.

Results of the TSD Calculations

As shown under the heading "TSD" of Attachment 1, soil concentrations for all radium and thorium isotopes computed using the two new recreational scenarios are much higher than similarly derived values using the rural residential, suburban residential, and commercial/industrial exposure scenarios described in the draft TSD.

---

[4] Summarized in a memorandum, *Reassessment of the Derived Concentration Guideline Level for Radium in Soil*, dated 16 January 1996 to H. Benjamin Hull (EPA-ORIA) from John Mauro (SC&A).

[5] EPA's current gamma shielding factor value of 0.8 is based on information presented in two Agency reports, *Natural Radiation in the United States* (ORP/SID 72-1; Oakley 1972) and *Population Exposure to External Natural Radiation Background in the United States* (ORP/SEPD-80-12; Bogen and Goldin 1981). EPA adopted 0.8 as the default value for the gamma shielding factor used in the development of risk-based preliminary remediation goals for radionuclides discussed in Part B of the *Risk Assessment Guidance for Superfund* (EPA/540/R-92/003; December 1991).

[6] *Residual Radioactive Contamination From Decommissioning: Technical Basis for Translating Contamination Levels to Annual Total Effective Dose Equivalent, Final Report.*, NUREG/CR-5512, PNL-7994, Volume I, Nuclear Regulatory Commission, June 1994.

Results of the Calculation A Analysis

Comparing the results of the TSD calculations with the Calculation A analysis shows that—for Ra-226, Ra-228, and Th-232—the TSD soil concentrations yielding an annual dose of 15 mrem EDE increase by a factor of 2-4. This increase results from simultaneously decreasing the contaminated zone area from the TSD default by factor of 100 (i.e., from 10,000 m^2 to 100 m^2) and decreased in thickness by a factor of 13 (i.e., fro· , 2 m to 0.15 m). Similarly, the results for the same radionuclides show that the annual dose rates for these radionuclides (except Th-230) at individual concentrations of 5 pCi/g in soil range from 2-25 mrem/yr EDE (column 7) for the Calculation A assumptions compared with 2-75 mrem/yr EDE based on the TSD defaults (column 6). The effects on Th-230 soil concentrations and dose rates are even more pronounced and are discussed below.

The bases for the Ra-226, Ra-228, and Th-232 results are readily explained. As shown in Table 3-1 (pp. 3-5 and 3-6) of the draft TSD, the doses from these radionuclides are almost entirely due to the external gamma radiation and plant pathways (excluding the radon pathway). Decreasing the thickness of the contaminated zone from 2 m to 0.15 m decreases the dose from the external pathway because the contribution to the gamma radiation field from radionuclides buried below 0.15 m is eliminated. Since RESRAD models a root zone depth of 0.9 m throughout which radionuclides are assumed to be absorbed, decreasing the thickness of the contaminated zone also reduces the amounts of radionuclides taken up by plants. Reducing the contaminated area reduces how much produce is grown onsite and ingested by individuals living on the site. In summary, by reducing the contaminated zone area and thickness—which in turn decreases the dose contributions from the external and plant pathways—the individual soil concentrations for Ra-226, Ra-228, and Th-232 yielding a dose rate of 15 mrem/yr EDE increase, although not in direct proportion to the changes in the contaminated zone area and thickness.

For Th-230, the results are not as easily explained. As shown in Table 3-1 of the draft TSD, the dose from Th-230 in soil (excluding the radon pathway) is due primarily to the external (70%) and plant (25%) pathways, and the maximum dose rate occurs in year 1,000. Since Th-230 is essentially a pure alpha-emitter, the external dose contribution (and most of the plant pathway contribution) for this nuclide is due to the ingrowth of Ra-226 and progeny over the 1,000 year time frame. This is possible because, over this time frame, the amount of radium and decay products produced and present in soil is greater than the amount of radium and thorium removed from soil by erosion and leaching. However, when the contaminated zone thickness is reduced to 0.15 m, the source erosion rate (0.001 m/yr) effectively removes the Th-230 faster than the time required for Ra-226 and progeny to grow in. Hence, the external and plant pathway doses from Th-230 are greatly reduced, and the maximum dose rate occurs at time zero. In summary, reducing the thickness of the contaminated zone for Th-230 effectively eliminates the ingrowth of Ra-226 plus progeny, which in turn greatly diminishes the dose contributions from the external and plant pathways. As a result, the soil concentration for Th-230 yielding a dose rate of 15 mrem/yr EDE increases by a factor of 21-43 (compare columns 3 and 4) when the soil thickness is reduced by a factor of 13 (i.e., from 2 m to 0.15 m).

Results of the Calculation B Analysis

The results of the Calculation B analysis are largely similar to those described above for the Calculation A assessment. This finding is in keeping with the fact that the two assessments are based on most of the same assumptions, including the reduced contaminated zone area and thickness. The further increase in the soil concentrations by a factor of approximately two for all radionuclides (except Th-230) listed under Calculation B compared with those under Calculation A is directly proportional to the reduction in the gamma shielding factor by a factor of 2 (i.e., from 0.8 to 0.4). For Th-230, the increase in soil concentrations from Calculation A to Calculation B is due to a combination of effects (i.e., the reduction in the gamma shielding factor and the modifications in the plant transfer factors for radium and lead).

Conclusions

This paper presents the results of a focused reassessment of derived soil concentrations and associated annual dose rates for selected isotopes of radium (Ra-226 and Ra-228) and thorium (Th-230 and Th-232) listed in 40 CFR 192. When examining sites cleaned up under 40 CFR 192, the Part 192 standards are generally comparable to the proposed 40 CFR 196 cleanup rule standard of 15 mrem/yr for Ra-226, Ra-228, and Th-232, and much more stringent for Th-230. For land uses other than residential, the Part 192 standards are more stringent than the proposed Part 196 standard. To further correlate the cleanup concentrations at a particular UMTRCA site to a dose level would require a site-specific determination that would take into consideration the physical characteristics of the site as well as the projected land use. EPA anticipates that these site-specific analyses would indicate that UMTRCA cleanups might result in lower actual dose rates than those calculated in the analyses presented in this paper.

Attachment 1. Radium and Thorium Soil Concentrations and Doses

Nuclide	Exposure scenario	Concentration (pCi/g) in soil yielding 15 mrem/yr EDE			Annual Dose Rate (mrem/yr EDE) Corresponding to 5 pCi/g in soil		
		TSD†	Calculation A*	Calculation B**	TSD	Calculation A*	Calculation B**
Ra-226	Rural Residential	1	4	8¶	75	19	9
	Suburban Residential	1	4	8¶	75	19	9
	Commercial/Industrial	5	11	20	15	7	4
	Recreational Playground	28	39	39	3	2	2
	Recreational Hunter/Fisher	18	26	30	4	3	3
Ra-228	Rural Residential	2	5	9	38	15	8
	Suburban Residential	2	5	9	38	15	8
	Commercial/Industrial	6	13	23	13	6	3
	Recreational Playground	33	47	47	2	2	2
	Recreational Hunter/Fisher	21	31	36	4	2	2
Th-230	Rural Residential	3	123	151	25	0.6	0.5
	Suburban Residential	5	215	409	15	0.3	0.2
	Commercial/Industrial	16	333	406	5	0.2	0.2
	Recreational Playground	94	1,737	1,737	0.8	0.04	0.04
	Recreational Hunter/Fisher	62	1,310	1,502	1	0.1	0.05
Th-232	Rural Residential	1	3	5	75	25	15
	Suburban Residential	1	3	7	75	25	11
	Commercial/Industrial	3	8	15	25	9	5
	Recreational Playground	19	33	33	4	2	2
	Recreational Hunter/Fisher	13	22	26	6	3	3

† Soil concentration data for the rural residential, suburban residential, and commercial/industrial exposure scenarios are taken from Table 7-1 (pp. 7-4 through 7-6) of the draft TSD. Data for the recreational playground and hunter/fisher scenarios are not provided in draft TSD; they were calculated using RESRAD Version 5.61 and the exposure factors in Attachment 2, as discussed in the text.

*Assumes all TSD default exposure parameter values for each respective scenario for a model site, except:
- the contaminated zone area is assumed to be 100 m^2, instead of the TSD value of 10,000 m^2
- the contaminated zone thickness is assumed to be 0.15 m, instead of the TSD value of 2 m.

**Same assumptions as in Calculation A, plus:
- the gamma shielding factor is assumed to be 0.4 (60%), instead of the TSD value of 0.8 (20%)
- the soil-to-plant transfer factor for Ra-226 is assumed to be 7.14E-03, instead of the TSD value of 4.0E-02
- the soil-to-plant transfer factor for Pb-210 is assumed to be 1.55E-03, instead of the TSD value of 1.0E-02.

¶ Given the same assumptions as in Calculation B, except that the contaminated zone is assumed to be equal to a typical 0.5-acre (2,023 m^2) lot size and that the contaminated zone thickness is assumed to be 0.3 m, the soil concentration for Ra-226 yielding 15 mrem/yr EDE is about 5 pCi/g for both the rural residential and suburban residential exposure scenarios.

Attachment 2. Exposure Parameter Values for the Recreational Playground and Hunter/Fisher Scenarios*

Parameter	Recreational Playground Scenario	Recreational Hunter/Fisher Scenario
Exposure pathways	1. External radiation exposure 2. Inhalation of contaminated dust 3. Ingestion of contaminated drinking water 4. Ingestion of contaminated soil	1. External radiation exposure 2. Inhalation of contaminated dust 3. Ingestion of contaminated drinking water 4. Ingestion of contaminated soil 5. Ingestion of contaminated meat 6. Ingestion of contaminated fish
Exposure frequency	140 d/y (i.e., 5 d/wk x 4 wk/mo x 7 mo/y)	30 d/y (i.e., 1 mo/y)
Exposure time	3 h/d outdoors; 0 h/d indoors	16 h/d outdoors; 8 h/d indoors
Inhalation rate	1,540 m^3/y (i.e., 11 m^3/d of contaminated dust x 140 d/y)	600 m^3/y (i.e., 20 m^3/d of contaminated dust x 30 d/y)
Drinking water rate	140 L/y (i.e., 1 L/d of contaminated water x 140 d/y)	60 L/y (i.e., 2 L/d of contaminated water x 30 d/y)
Meat ingestion rate	Not applicable	2.25 kg/y (i.e., 0.075kg/d x 30 d/y)
Fish ingestion rate	Not applicable	1.62 kg/y (i.e., 0.054 kg/d x 30 d/y)
Indoor/outdoor inhalation shielding factor	Not applicable	0.8 (20% shielding)
Feed storage times	Not applicable	0 days

*All other parameter values not shown are identical to those specified in the draft TSD for the rural residential exposure scenario using the RESRAD computer code.